

****Volume Title****

*ASP Conference Series, Vol. ****Volume Number*****

****Author****

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Polar structures in late-type galaxies

Alexei Moiseev

*Special Astrophysical Observatory, Russian Academy of Sciences, Nizhnij
Arkhyz, Russia*

Abstract. A common point of view is that stable polar structures are mainly present in the E/S0 early-type galaxies lacking dense gas in their host disks. However, nuclear, as well as external polar rings and disks also exist in the late-type hosts, including gas-rich dwarf galaxies. Using the 3D spectroscopic observations of these objects we can derive the rotation properties of the gas components separately in the main and polar planes. The most detailed picture of the gas kinematics and mass distribution properties could be obtained from the combination of optical (H II) and radio (H I) data sets. I briefly review the results of such studies, including the observations of the direct interaction between the multi-spin gas components.

1. Introduction

When talking about a polar ring galaxy (PRG), we usually imply a system, where a central early morphological type red galaxy is surrounded by a ring, similar to the late-type objects, having blue colors and containing gas and young stellar population: “*..in all PRGs the H I gas is associated with the polar structure and not with the central stellar spheroid...*” (Iodice et al. 2006). Indeed, in the case of early-type central objects the matter accreted from the environment with an orthogonal orientation of the orbital moment has never experienced any direct collisions with the pre-existing ISM. However late-type hosts also exist among PRGs (van Driel et al. 1995, and references below). The SDSS-based catalog of PRG candidates (Moiseev et al. 2011) lists the galaxies, where both components with different spins have relative blue colors, i.e. posses H II regions and young stellar population: SPRC 52, SPRC 171, SPRC 269, etc. These examples show that the interaction between two gaseous subsystems does not dramatically destroy the global structure of a large-scale polar disk, at least in some objects. In contrast with external polar rings where the most of the central galaxies are E/S0, the inner polar structures (IPS) nested in a wide range of morphological types: about 30% of confirmed IPS are observed in the Sb–Im galaxies (Moiseev 2012). This implies a larger real fraction of late-type PRGs, as the inner and large-scale polar structures form a single family in the distribution of normalized diameters, but the methods of candidate selection vary (image inspection for PRGs, study of circumnuclear kinematics for IPS).

For a long time PRGs are considered to be a good probe to study the dark matter 3D-shape (Whitmore, McElroy, & Schweizer 1987; Iodice et al. 2003). In the case of “classical” PRGs, special attempts are needed to reconstruct the circular rotation curve from the early-type galaxy stellar kinematics: deep absorption-line spectroscopy

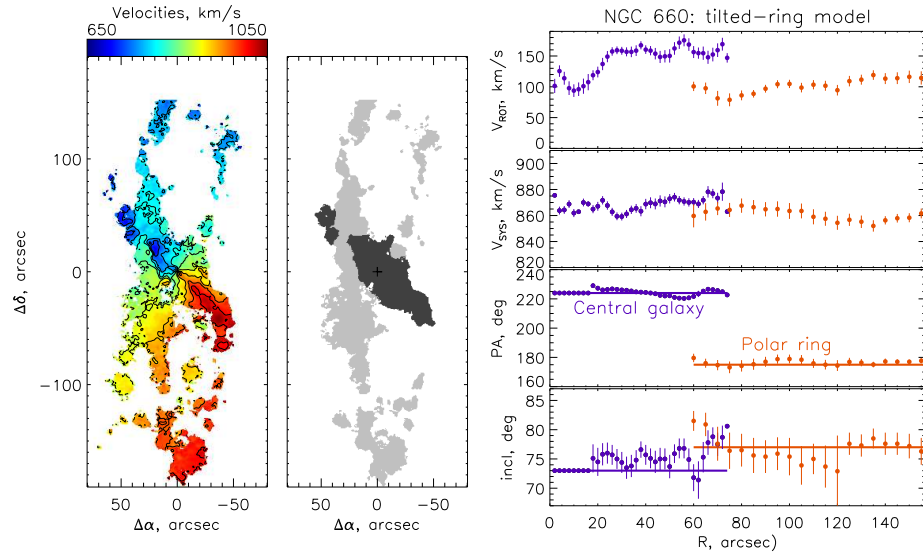


Figure 1. Ionized gas kinematics in NGC 660: left – the $H\alpha$ velocity field obtained at the SAO RAS 6-m telescope with the scanning FPI; middle – the subdivision of this field into the domains of the inner disk (dark gray) and polar ring (light shaded). The right plot shows the results of tilted-ring analysis for both kinematical components: radial variation of the rotation velocity, systemic velocity, position angles and inclination. The solid lines mark the accepted values of PA and i .

and subsequent asymmetric-drift correction which depends on the accepted dynamical model parameters and quality of velocity dispersion measurements. In contrast with early-types hosts, rotation curves of both components in the late-type PRG could be reconstructed from the emission-line velocity field derived from the radio interferometric observations of neutral and molecular gas, or optical observations in the ionized gas emission lines with scanning Fabry-Perot interferometers (FPI) or other 3D-spectroscopy devices.

2. Two gaseous rotating components

Fig. 1 shows the velocity field of ionized gas in NGC 660 derived from the observation at the SAO RAS 6-m telescope with the scanning FPI in the SCORPIO focal reducer (Afanasiev & Moiseev 2005). Using the tiled-rings approximation we were able to study separately the kinematics of the central disk and the external structure, which is inclined by the angle of about 50° to the main disk. The ring of ionized gas is flat ($PA, i \approx const$), while a warp is observed in the $H\text{ I}$ for the larger radii (van Driel et al. 1995). The maximal rotation velocity of the central disk is about 1.5 times larger than that of the ring. Such behaviour contradicts with the common trend of PRGs where the rings rotate faster than the hosts, as it follows from their position on the Tully-Fisher diagram (Iodice et al. 2003; Combes, Moiseev, & Reshetnikov 2013). Now we are matching the ionized gas kinematics with the new WSRT $H\text{ I}$ data to estimate of the dark matter shape in NGC 660.

The interesting examples of gas rotation in both planes are the post-merger systems like UGC 5600 (Shalyapina et al. 2007), Arp 230 and MCG -5-7-1 (Schiminovich et al. 2013). Based on the properties of H I kinematics in two latter galaxies, the authors claimed that the dark halo potential is spherical, with only 5 – 10% flattening.

3. Streams interaction and gas ionization state

The analysis of NCG 660 velocity field demonstrates an overlapping of the central disk and the ring at the distances $r \approx 60\text{--}75''$ (4–5 kpc). It means that the orbits of matter with different spins have intersected. Moreover, gaseous clouds can avoid meetings at these cross ways during many revolutions, because only a few HII regions are located on the overlapping radii. Also, the width of the “collision zone” depends on the orbits ellipticity. The more intriguing case is the Arp 212 galaxy which provides the evidence of direct collisions between the ISM in the main galaxy plane and in the internal part of the inclined polar ring: a peculiar dust lane is observed in the region where the orbits (calculated from FPI velocity field analysis) intersect each other (Moiseev 2008). The integral-field observations of this galaxy also point to a possible contribution of shocks into the gas ionization, as it follows from the emission-line ratio maps $[\text{N II}]/\text{H}\alpha$ (García-Lorenzo et al. 2008) and $[\text{O III}]/\text{H}\beta$ (Cairós et al. 2012) for the region of the matter collision. In this case the shock fronts related with the interaction between multi-spin gaseous components provoke the formation of dense molecular clouds and trigger the burst of star formation observed in Arp 212 now.

The shock waves should be formed in the classical PRGs too. Wakamatsu (1993) suggested that the gas on the polar orbits should experience shocks passing through the gravitational well of the stellar disk, even in the case at the central disk lacks gas. Unfortunately, direct observation of shocks in PRGs is still an open question, while the shock contribution in the gas ionization is crucial for the gas metallicity estimation using emission lines ratios.

Some circumstantial evidences of shock waves formation among PRGs are provided by the recent studies of tilted gaseous disks accreted from the galactic environment. The spectroscopic observation of NGC 7743 have discovered a disk of ionized gas inclined by 33° or 77° to the stellar one (Katkov, Moiseev, & Sil’chenko 2011) with the domination of shock waves in the gas emission lines excitation. The similar effect is also found in non-coplanar gaseous disks of isolated lenticular galaxies (Katkov, Sil’chenko, & Afanasiev 2013). An alternative mechanism providing LINER-like emission is the ionization by post-AGB stars (Sarzi et al. 2010). New spectral observations including detection of faint emission lines are crucial for the final conclusion.

4. Polar structures in dwarf galaxies

A traditional way of new PRG search consists in collecting the candidates with the corresponding optical morphology (Whitmore et al. 1990; Moiseev et al. 2011) and the follow-up observations of their kinematics. Dwarf star forming galaxies (dIrr, blue compact dwarf galaxies, H II-galaxies) are a more difficult case, because the irregular distribution of bright knots is usually a dominating feature in the optical/NIR images. It’s not surprising that a discovery of polar structures in many dwarf galaxies is a byproduct of study of the H II or H I velocity fields: SDSS J102819.24+623502.6

(Stanonik et al. 2009), Mrk 370 (Moiseev 2011), DDO 99 and UGC 8508 (Moiseev 2014). A serious problem is that the velocity pattern in the expanding bubbles around the sites of star formation can mimic the kinematic behaviour of multi-spin structures (see the Appendix in Moiseev, Pustilnik, & Kniazev 2010). Additional information (velocity dispersion distribution, UV/optical/NIR morphology) is needed for a final conclusion.

It is believed that interactions are the main mechanism which provokes bursts of star formation in many dwarf galaxies. It means that a large fraction of polar structures in these galaxies is related with the same interaction event (accretion or merging). For instance, at least 18% of nearby luminous blue compact dwarf galaxies in the sample of 28 objects possess external and inner polar structures (see the references in Moiseev 2011). Surveys of kinematics of galaxies with large field of view IFU will discover new examples of such systems.

Acknowledgments. The work was supported by the RFBR grant 13-02-00416 and the “Active Processes in Galactic and Extragalactic Objects” basic research program of the Department Physical Sciences of the RAS OFN-17. I am also grateful to the ‘Dynasty’ Foundation. The observations at the 6-m telescope were carried out with the financial support of the Ministry of Education and Science of Russian Federation (contracts no. 16.518.11.7073 and 14.518.11.7070).

References

- Afanasiev, V. L., & Moiseev, A. V. 2005, *Astronomy Letters*, 31, 194
 Cairós, L. M., Caon, N., García Lorenzo, B. et al. 2012, *A&A*, 547, A24
 Combes, F., Moiseev, A., & Reshetnikov, V. 2013, *A&A*, 554, A11
 García-Lorenzo, B., Cairós, L. M., Caon, N., Monreal-Ibero, A., & Kehrig, C. 2008, *ApJ*, 677, 201
 Iodice, E., Arnaboldi, M., Bournaud, F. et al. 2003, *ApJ*, 585, 730
 Iodice, E., Arnaboldi, M., Saglia, R. P. et al. 2006, *ApJ*, 643, 200
 Katkov, I. Y., Moiseev, A. V., & Sil’chenko, O. K. 2011, *ApJ*, 740, 83
 Katkov, I., Sil’chenko, O., & Afanasiev, V. 2013, *MNRAS*, accepted. 1312.6701
 Moiseev, A. 2011, in *EAS Publications Series*, edited by M. Koleva, P. Prugniel, & I. Vauglin, vol. 48 of *EAS Publications Series*, 115
 Moiseev, A. V. 2008, *Astrophysical Bulletin*, 63, 201
 Moiseev, A. V. 2012, *Astrophysical Bulletin*, 67, 147
 Moiseev, A. V. 2014, *Astrophysical Bulletin*, 69, in press
 Moiseev, A. V., Pustilnik, S. A., & Kniazev, A. Y. 2010, *MNRAS*, 405, 2453
 Moiseev, A. V., Smirnova, K. I., Smirnova, A. A., & Reshetnikov, V. P. 2011, *MNRAS*, 418, 244
 Sarzi, M., Shields, J. C., Schawinski, K. et al. 2010, *MNRAS*, 402, 2187
 Schiminovich, D., van Gorkom, J. H., & van der Hulst, J. M. 2013, *AJ*, 145, 34
 Shalyapina, L. V., Merkulova, O. A., Yakovleva, V. A., & Volkov, E. V. 2007, *Astronomy Letters*, 33, 520
 Stanonik, K., Platen, E., Aragón-Calvo, M. A. et al. 2009, *ApJ*, 696, L6
 van Driel, W., Combes, F., Casoli, F. et al. 1995, *AJ*, 109, 942
 Wakamatsu, K.-I. 1993, *AJ*, 105, 1745
 Whitmore, B. C., Lucas, R. A., McElroy, D. B., Steiman-Cameron, T. Y., Sackett, P. D., & Olling, R. P. 1990, *AJ*, 100, 1489
 Whitmore, B. C., McElroy, D. B., & Schweizer, F. 1987, *ApJ*, 314, 439